



D3SJ Talk

The Latest on the Thorium Cycle as a
Sustainable Energy Source

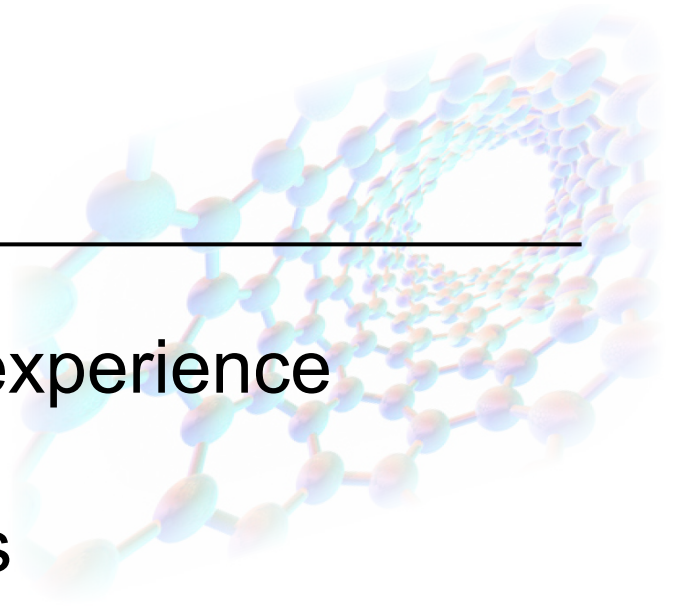
Philip Bangerter

4 May 2011

About the Speaker

Philip Bangerter

- Process Engineer of 30 years experience
 - Mining industry
 - Sustainability in design, 8 years
-
- Employed currently in an employee-owned engineering consultancy
 - Globally 8,500 employees; 1800 in Australia



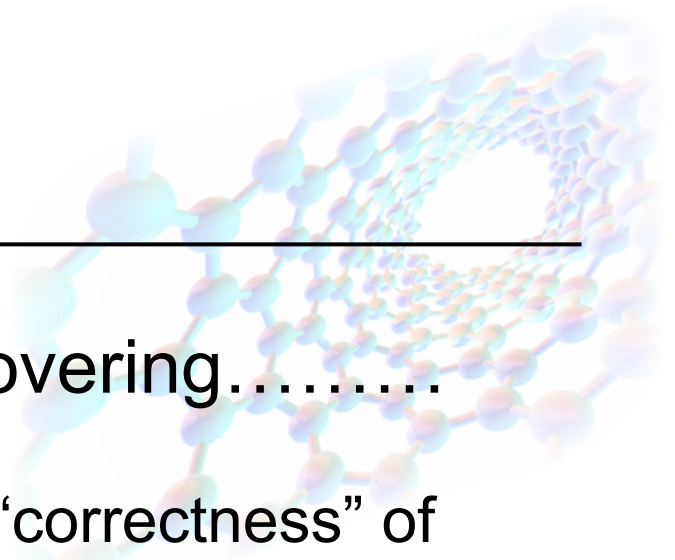
Summary

Covering.....

- Claims to Sustainability
- Periodic Table & Fission
- Basic Reactor Designs
- Sources of Thorium in ores
- Thorium Reactors in Operation
- Embodied Energy
- Discussion Points

Not Covering.....

- The “correctness” of pursuing an energy alternative
- The detail of reactor design
- Accidents

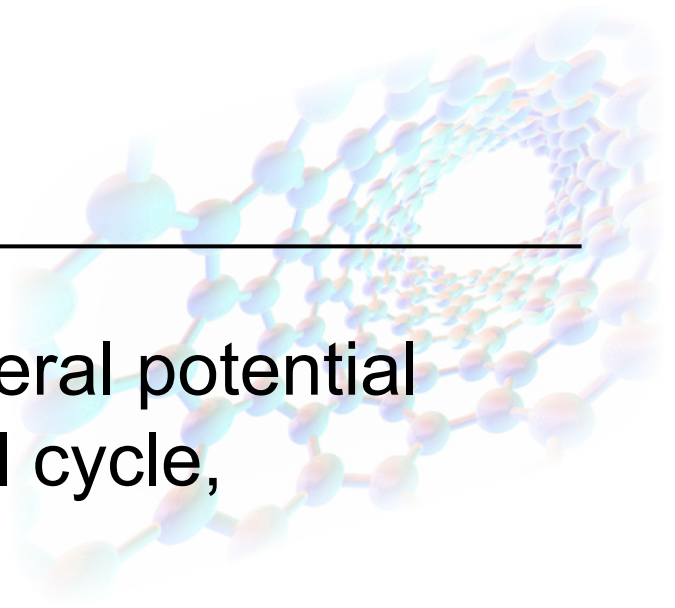


Claims

Potential advantages over Uranium

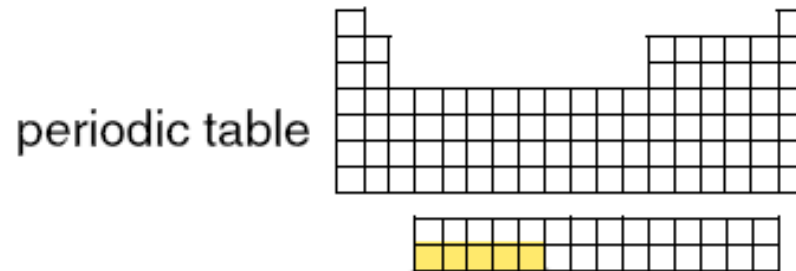
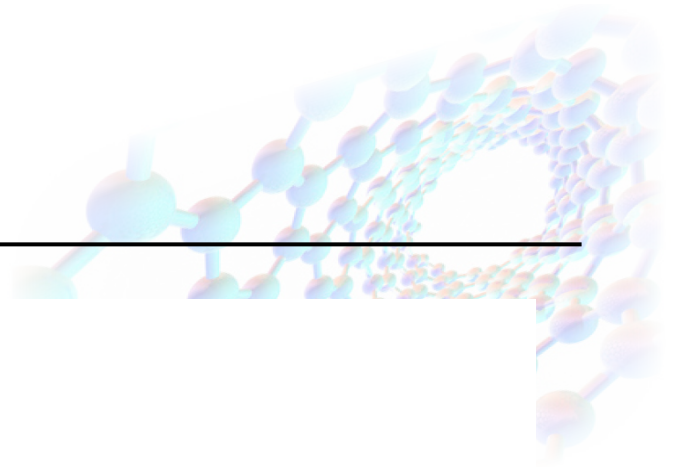
The thorium fuel cycle claims several potential advantages over a uranium fuel cycle, including:

- greater abundance (about 4 times);
- superior physical and nuclear properties;
- enhanced proliferation resistance;
- reduced plutonium & actinide production; &
- the ability to “burn” nuclear wastes materials.



Periodic Table

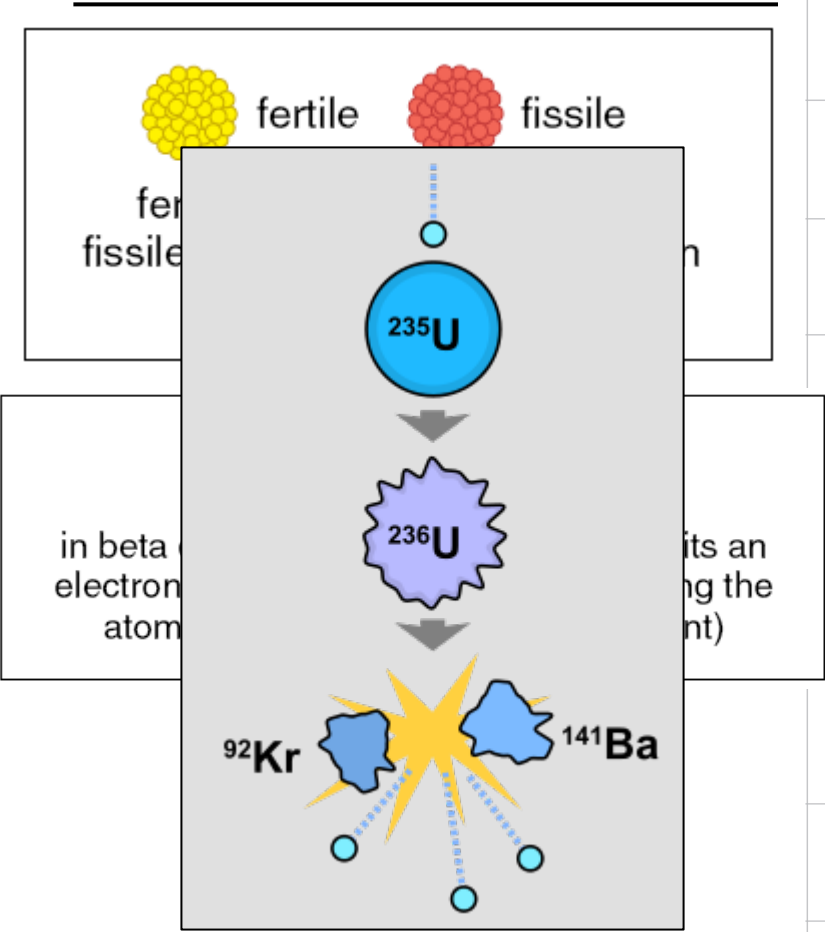
Thorium, Uranium and the Transuranics



atomic number (number of protons)

thorium (Th) 90	protactinium (PA) 91	uranium (U) 92	neptunium (Np) 93	plutonium (Pu) 94
-----------------------	----------------------------	----------------------	-------------------------	-------------------------

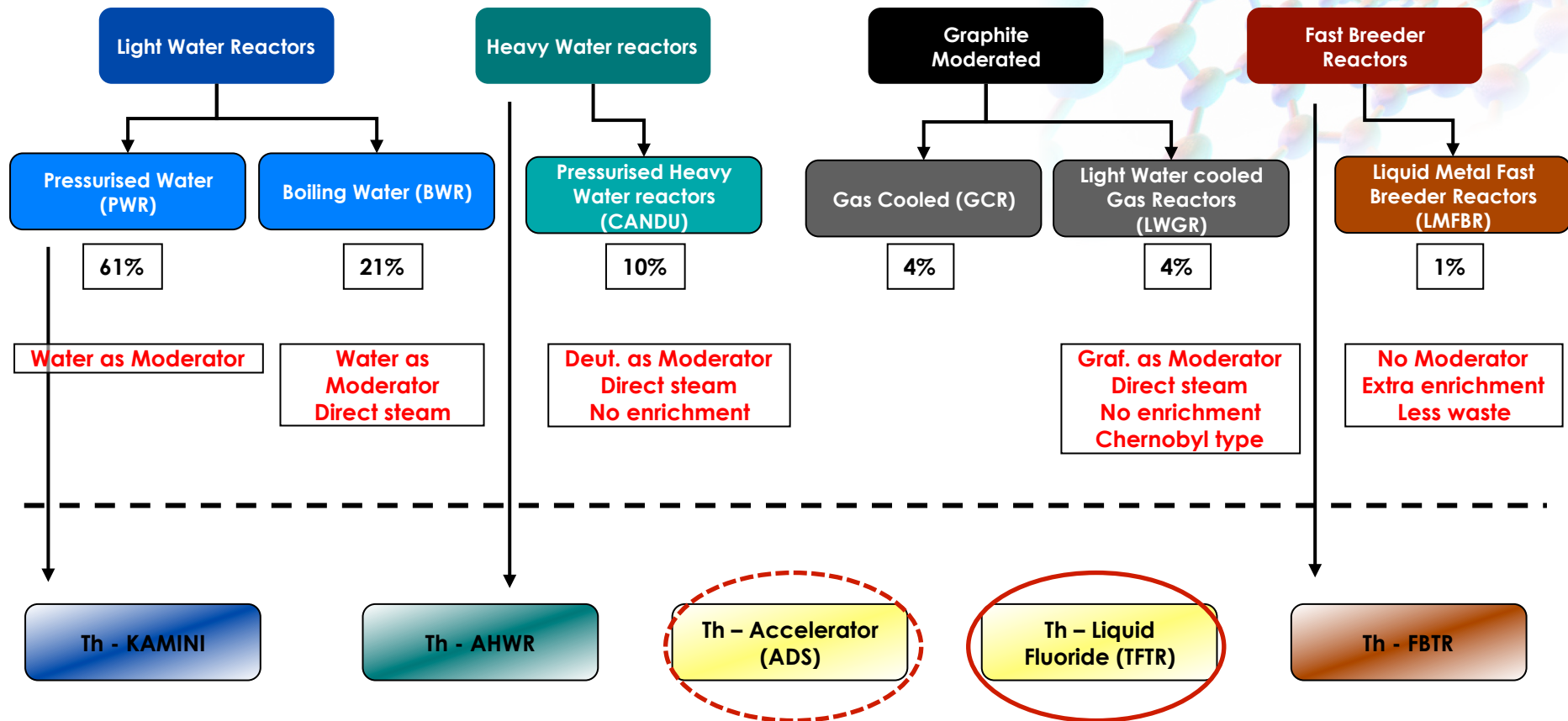
Fission



isotope number (protons + neutrons)	thorium (Th) 90	protactinium (PA) 91	uranium (U) 92	neptunium (Np) 93	plutonium (Pu) 94
241					
240					
239					
238			absorbs neutron		
237					
236					
235					
234					
233					
232			absorbs neutron		

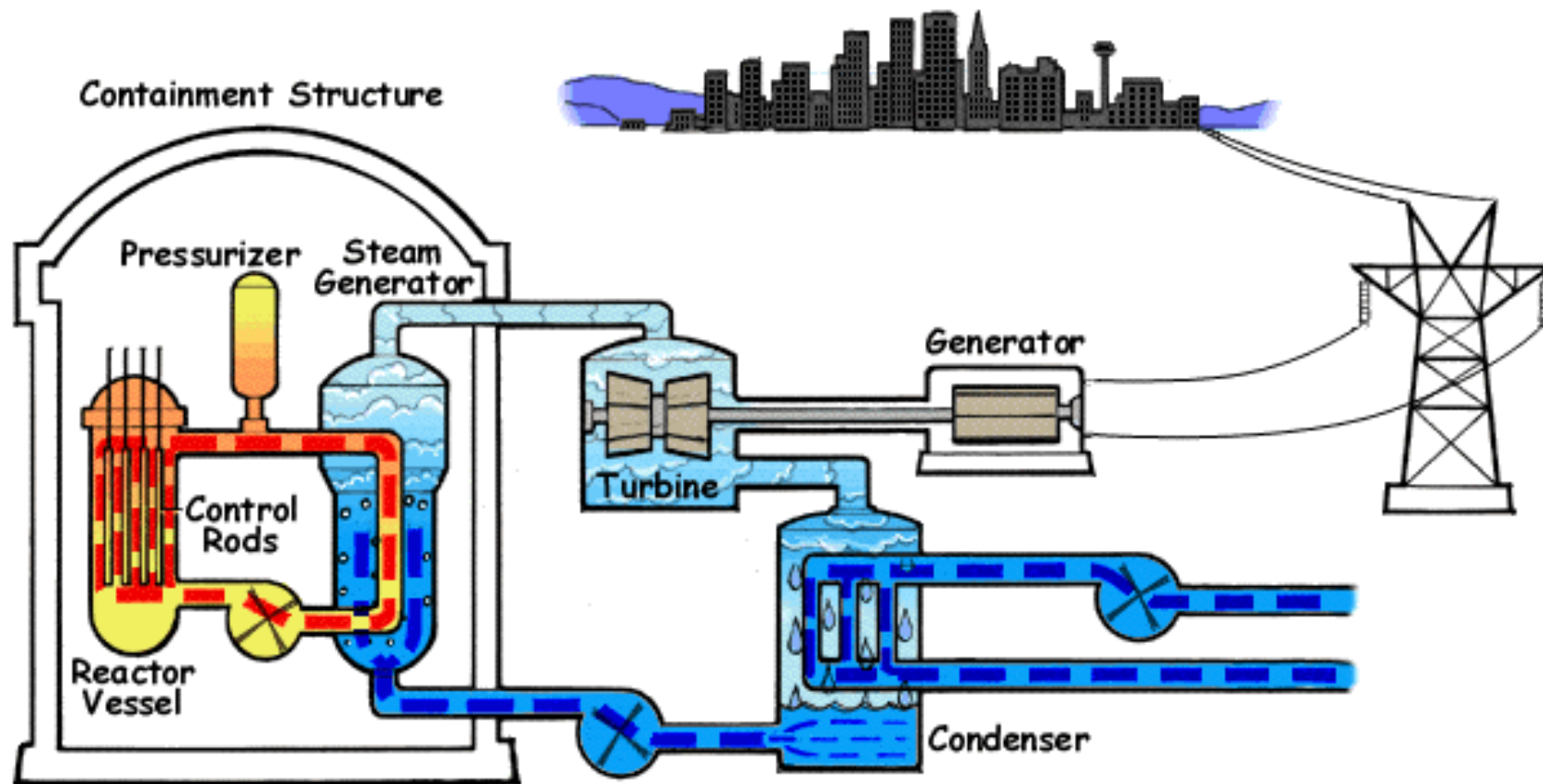
Nuclear Reactor Types

Thorium Fuel Applicability



Schematics of Designs

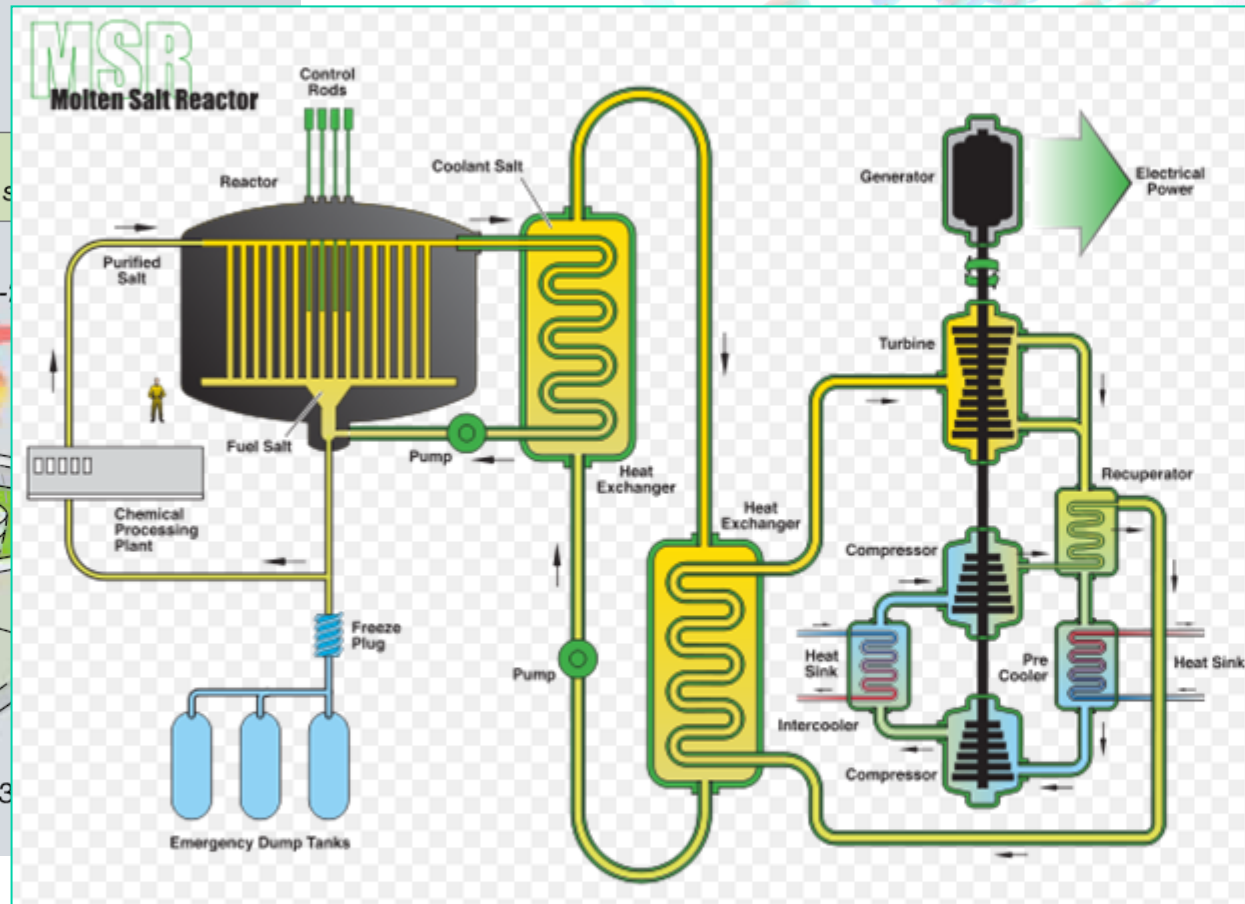
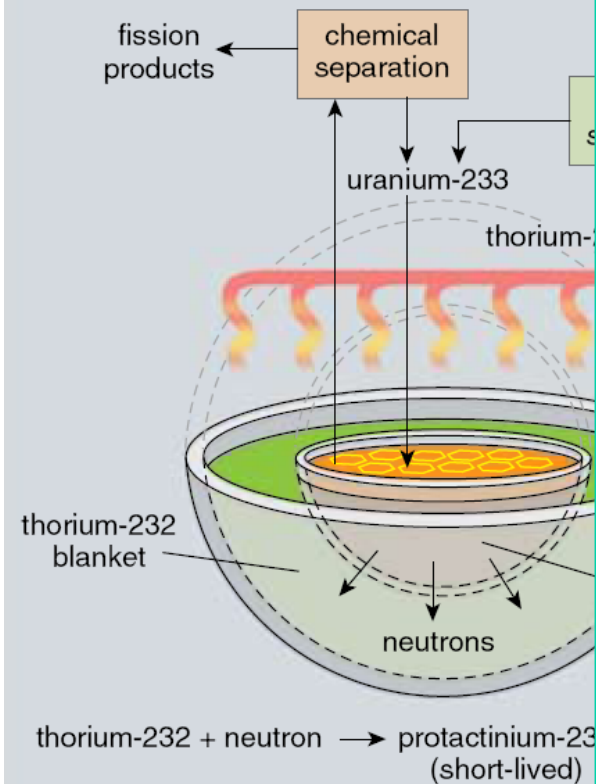
U-Pu Light Water



Schematics of Designs

Th Liquid Fluoride

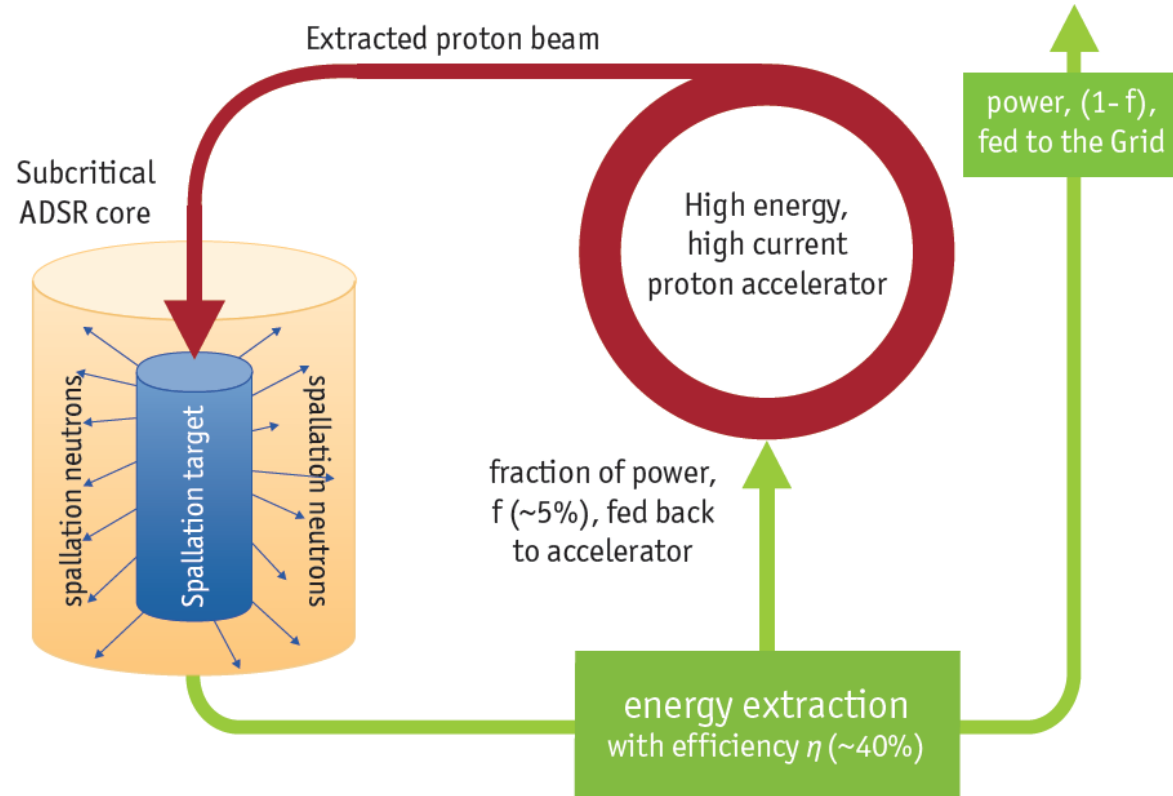
liquid fluoride thorium reactor



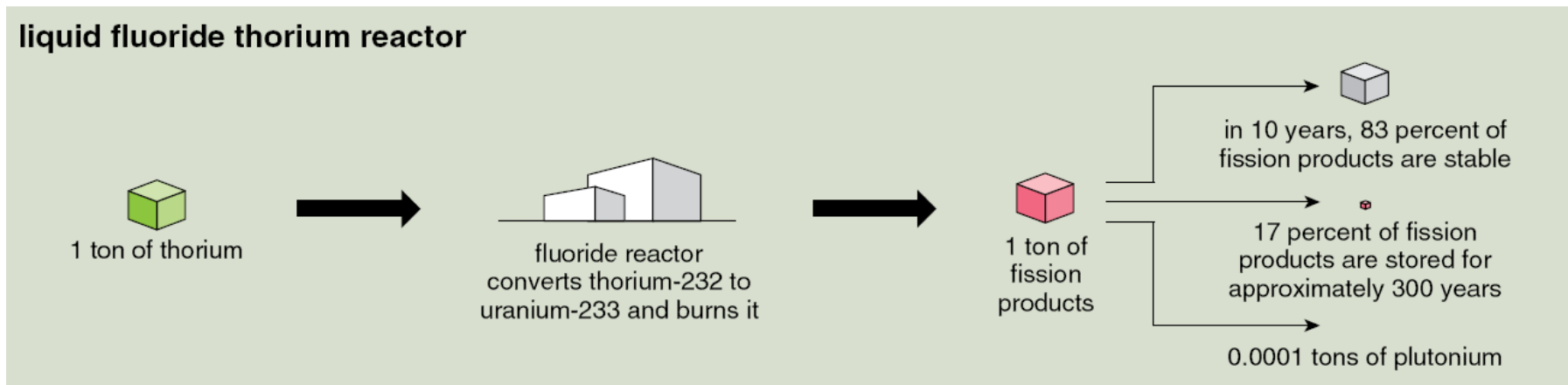
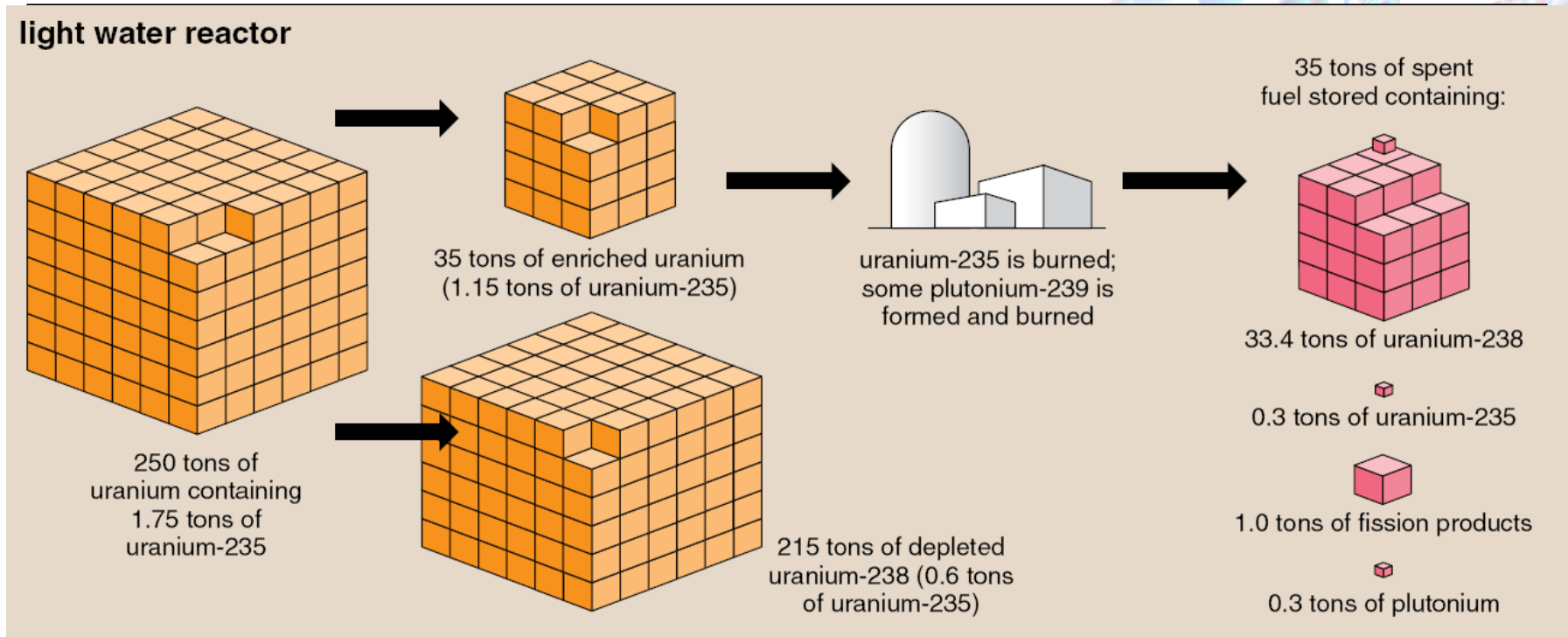
Schematics of Designs

The Accelerator-driven System (ADS)

- Expensive (Capital)
- Existing technologies
- Inherent safety

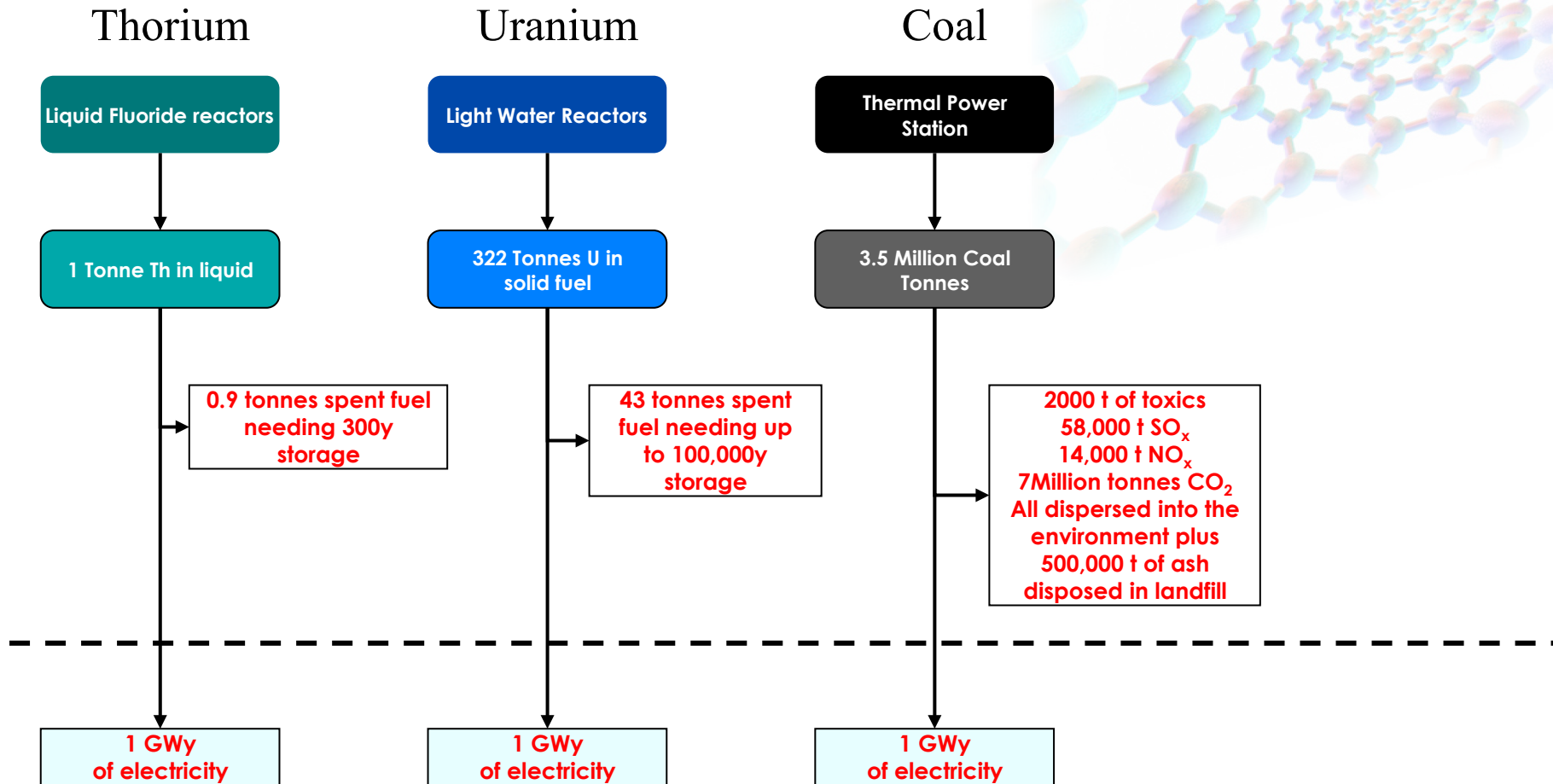


Waste products



Rule-of-Thumb

Thorium Fuel vs. Alternatives



Resources

Disposition by Country

Reports vary, but
in summary,
Thorium
Reserves are
widely distributed

Estimated thorium resources by country

Country	Total Identified Thorium Resources (‘000 t TH) <USD 80/kg TH	
		%
Australia	420	17
United States	400	16
Turkey	344	14
India	319	13
Venezuela	300	12
Brazil	221	9
Norway	132	5
Egypt	100	4
Russian Federation	75	3
Greenland	54	2
Canada	44	2
South Africa	18	1
Others	33	1
Total	2460	

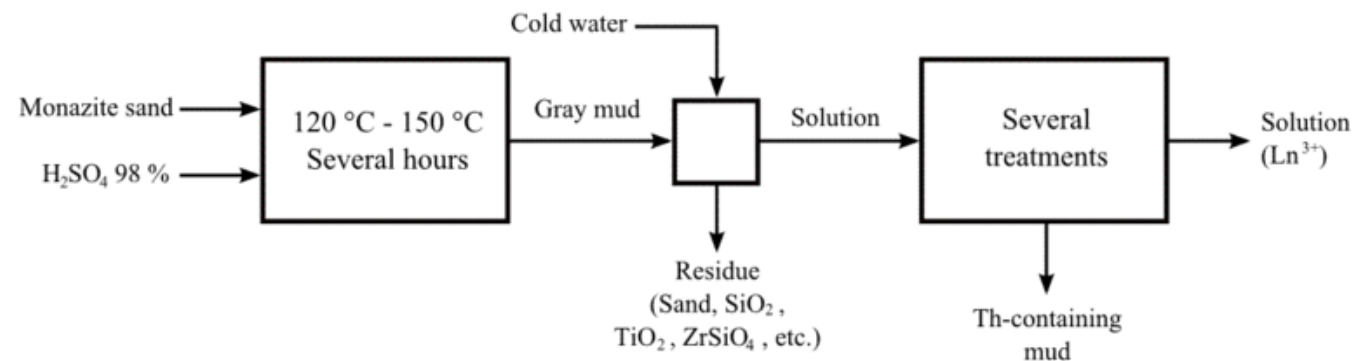
Sources: Data for Australia compiled by Geoscience Australia; estimates for all other countries are from: OECD, 2006: Red Book Retrospective. A review of Uranium Resources, Production and Demand from 1965 to 2003.

Sources of Th

Thorite hard rock vs. Beach Sand based Monazite

Thorium occurs in several minerals including thorite (ThSiO_4), thorianite ($\text{ThO}_2 + \text{UO}_2$) and monazite.

Today's production of Thorium is from Monazite; Australia is a leading producer of Monazite (as a waste).



Existing Th Reactors

Page 1

Name and Country	Type	Power	Fuel	Operation Period
AVR, Germany	HTGR Experimental (Pebble Bed Reactor)	15 MW _e	Th & U-235 Driver Fuel, Coated fuel particles, Oxide & dicarbides	1967 - 1988
THTR, Germany	HTGR Power (Pebble Type)	300 MW _e	Th & U-235 Driver Fuel, Coated fuel particles, Oxide & dicarbides	1985 - 1989
Lingen, Germany	BWR Irradiation-testing	60 MW _e	(Th, Pu)O ₂ Test Fuel , Pellets	Terminated in 1973
Dragon, UK OECD-Euratom also Sweden, Norway & Switzerland	HTGR Experimental (Pin-in-Block Design)	20 MW _{th}	Th & U-235 Driver Fuel, Coated fuel particles, Dicarbides	1966 -1973
Peach Bottom, USA	HTGR Experimental (Prismatic Block)	40 MW _e	Th & U-235 Driver Fuel, Coated fuel particles, Oxide & dicarbides	1966 – 1972
Fort St Vrain, USA	HTGR Power (Prismatic Block)	330 MW _e	Th & U-235 Driver Fuel, Coated fuel particles, Dicarbides	1976 – 1989
MSRE ORNL, USA	MSBR	7.5 MW _{th}	U-233 Molten Fluorides	1964 – 1969

Existing Th Reactors

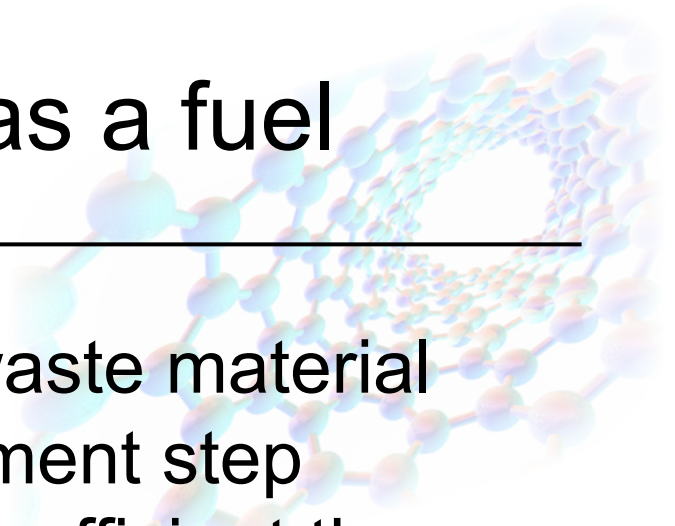
Page 2

Borax IV & Elk River Reactors, USA	BWRs (Pin Assemblies)	2.4 MW _e 24 MW _e	Th & U-235 Driver Fuel, Oxide Pellets	1963 – 1968
Shippingport & Indian Point, USA	LWBR PWR (Pin Assemblies)	100 MW _e 285 MW _e	Th & U-233 Driver Fuel, Oxide Pellets	1977 – 1982 1962 – 1980
SUSPOP/KSTR KEMA, Netherlands	Aqueous Homogenous Suspension (Pin Assemblies)	1 MW _{th}	Th & HEU Oxide Pellets	1974 - 1977
NRU & NRX, Canada	MTR (Pin Assemblies)		Th & U-235 Test Fuel	Irradiation-testing of few fuel elements
KAMINI, CIRUS & DHRUVA, India	MTR Thermal	30 kW _{th} 40 MW _{th} 100 MW _{th}	Al & U-233 Drive Fuel, 'J' rod of Th & ThO ₂ 'J' rod of ThO ₂	All three research reactors in operation
KAPS 1 & 2, KGS 1 & 2, RAPS 2, 3 & 4, India	PHWR (Pin Assemblies)	220 MW _e	ThO ₂ Pellets For neutron flux flattening of initial core after start-up	Continuing in all new PHWRs
FBTR, India	LMFBR (Pin Assemblies)	40 MW _{th}	ThO ₂ blanket	In operation

Characteristics of Thorium as a fuel

Advantages

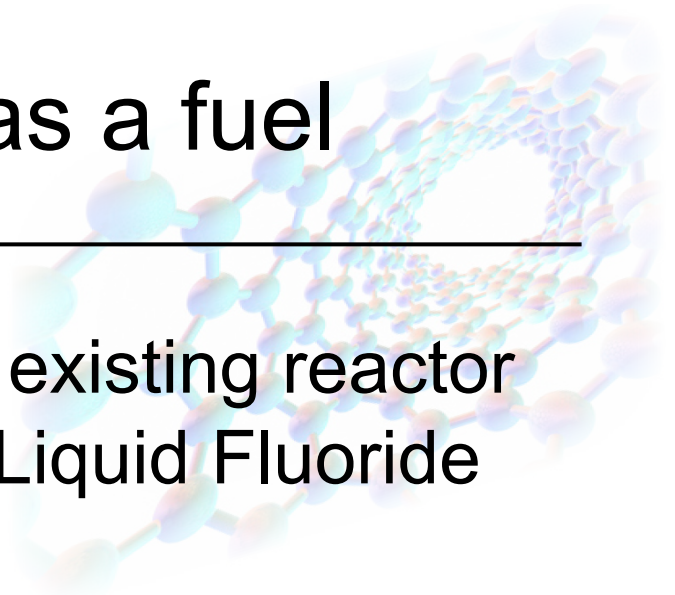
- Th extracted from an existing waste material
- Single isotope excludes enrichment step
- Fertile conversion of Th is more efficient than U
- ThO_2 is more stable than its U equivalent and does not further oxidise
- The radiological hazards are far lower than U; less transuranics are produced



Characteristics of Thorium as a fuel

Disadvantages

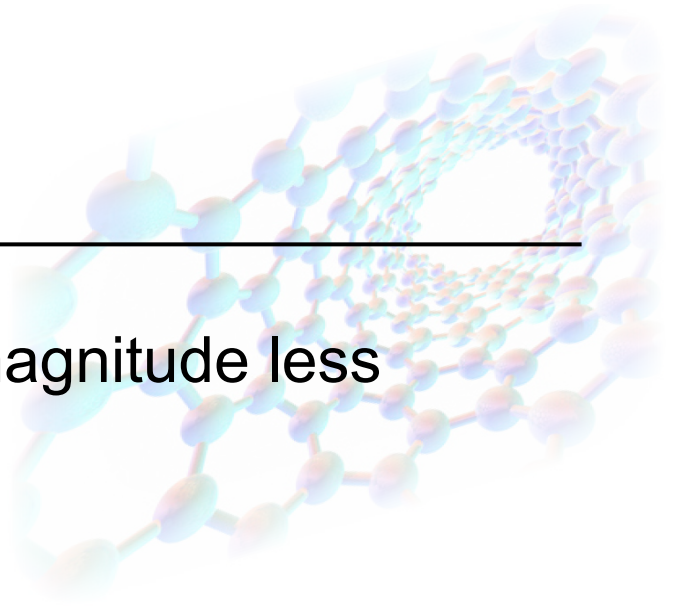
- Th is not easily substituted into existing reactor types; requires the adoption of Liquid Fluoride or Accelerator designs
- There is no existing industry, like Uranium; development times are somewhat lengthy due to technical risks
- There is no weapons-relevant by-product, so no military funding



Proliferation Risk

Th cycle vs. U cycle

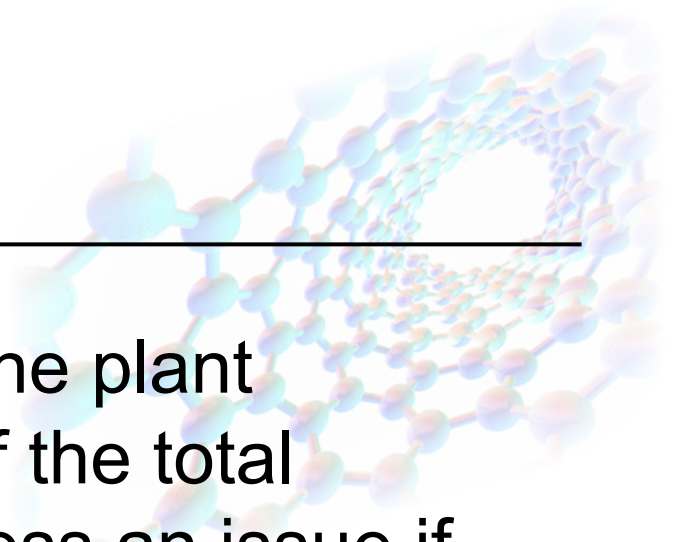
- Th cycle proliferation risk is orders of magnitude less because:
- Thorium is not fissile
 - There is no enrichment step
 - The fissile material that can be produced leaves an obvious “signature” (U-233 is contaminated with U-232 from which it can not be chemically separated and has several decay products which emit high energy gamma radiation).
 - A liquid fluoride design negates U-232 extraction



Embodied Energy Question

Thorium vs. true renewables – rules-of-thumb

- The embodied energy (EE) of the plant structures is a tiny proportion of the total operating energy; this is even less an issue if the EE is from “green” sources
- A Thorium facility will have significantly less EE than a wind or solar facility per kW/h
- Plant turnover is 20-40 years
- The EE of the fuel source is relevant



Discussion Point summary

- For society
 - A viable carbon-effective energy source
 - A safer option than Uranium
 - May even help existing waste disposal
 - Uses an existing waste product

